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Emerging Failures in Gas Turbine Engines Operating in Hot Environments

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Authors Bios

Kaartik Palaniappan *is currently a Senior Machinery Engineer within the Machinery and Power Group for EMEPMI supporting its biggest asset. Prior to this assignment he was the Program Owner for Crane & Lifting Equipment and prior to that he was the Program Owner for Machinery Equipment. He has a combined Machinery technical experience of about 11 years.*

Stan Uptigrove *is the Asia Regional Machinery Advisor for EMEPMI. Prior to this assignment he was Team Lead for Machinery at ExxonMobil Upstream Research Company. He started his 36 year career at Nova Corporation in Canada where he was responsible for many of the world's first applications of gas seals and magnetic bearings to turbo-machinery. Mr. Uptigrove was one of the founders and senior management of Revolve Technologies Inc. and was also the Global Director at Flowserve Corporation managing their gas seal and new pump seal business.*

Steve Broomfield *is currently Senior Key Expert within Services Engineering at Siemens ITC. Prior to this he held roles in gas turbine development, test operations and project engineering. He has 39 years experience in gas turbine engineering.*

Camille Rizzetto *is currently Service Engineer within the Solution Engineering team (Gas Turbine) in Siemens ITC*

Abstract

Two (2) gas turbine engines operating offshore experienced Domestic Object Damage (DOD) failure with damaged blades in the HP compressor section.

*The failures were caused by repeated use of a component undergoing **wear accelerated by hot ambient environment (tropical climate) and operating in full load**. A variety of different failure modes and how the root cause was determined is presented.*

The current solution to prevent failures is to replace the component during engine overhaul. The component is the shroud box which holds the 7th Stage Outlet Guide Vane (OGV) of the engine's IP compressor section.

*Risk exposure for the remaining fleet was analyzed **to prevent repeat failure** and improvements were made on the online algorithm to provide earlier indication of a potential failure.*

7^{th} Stage Outlet Guide Vane (OGV) of Engine IP Compressor

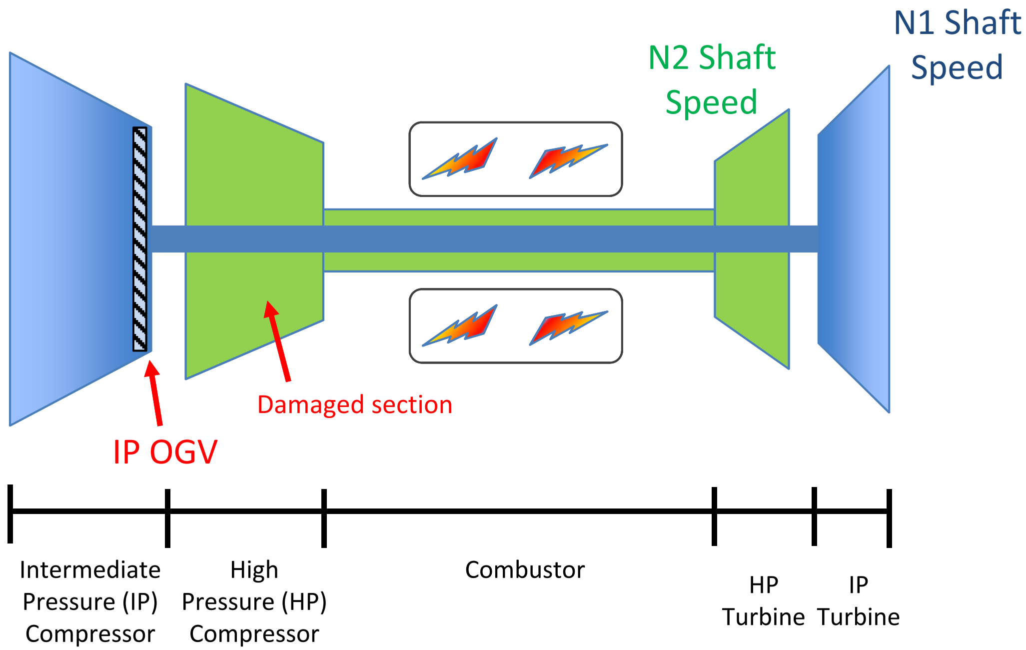

Fig 1: Schematic of Engine Assembly

View of IP OGV assembly

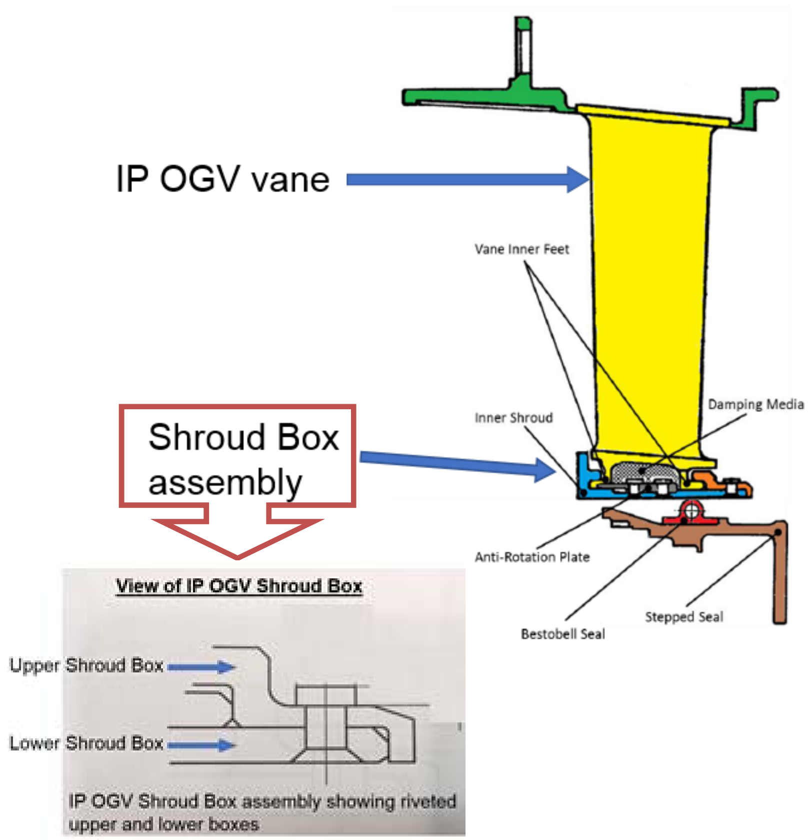

Fig 2: View of Shroud Box & IP OGV Assembly

Problem Statement

- The current design of the low / intermediate pressure (IP) compressor's outlet guide vane (OGV) was introduced in the early 2000s.
- There has been a few recent IP OGV failures on similar model engines operating in hot climate but no prior fleet wide identification of potential issue.
- 2 engine failed recently (First failed in Aug'16 and second in Feb'17). OEM has seen a total of 7 engine failures out of 300 units operating 1 million run-hours.
- Cause was not known but degradation of the damping rubber was suspected as a contributing factor.
- Joint teardown & investigation with OEM and authorized repair centre revealed that the root cause was related to excessive wear on the OGV shroud box, not identified during overhaul.
- The reuse of shroud box (that would now be replaced as a result of improved inspection procedures) resulted in failure of the OGV during operation once the damping media deteriorated.
- The failure of the OGV resulted in OGV debris being injected into the airstream resulting in high pressure compressor (HPC) blade damage
- This problem was detected despite the high reliability of the fleet.
- This case applies to engines operating in extreme conditions (hot climate and continuous full power)

IP OGV Failure

Engine 1: IP OGV Damping media breakdown combined with shroud box wear leading to OGV failure resulting in engine Domestic Object Damage (DOD).

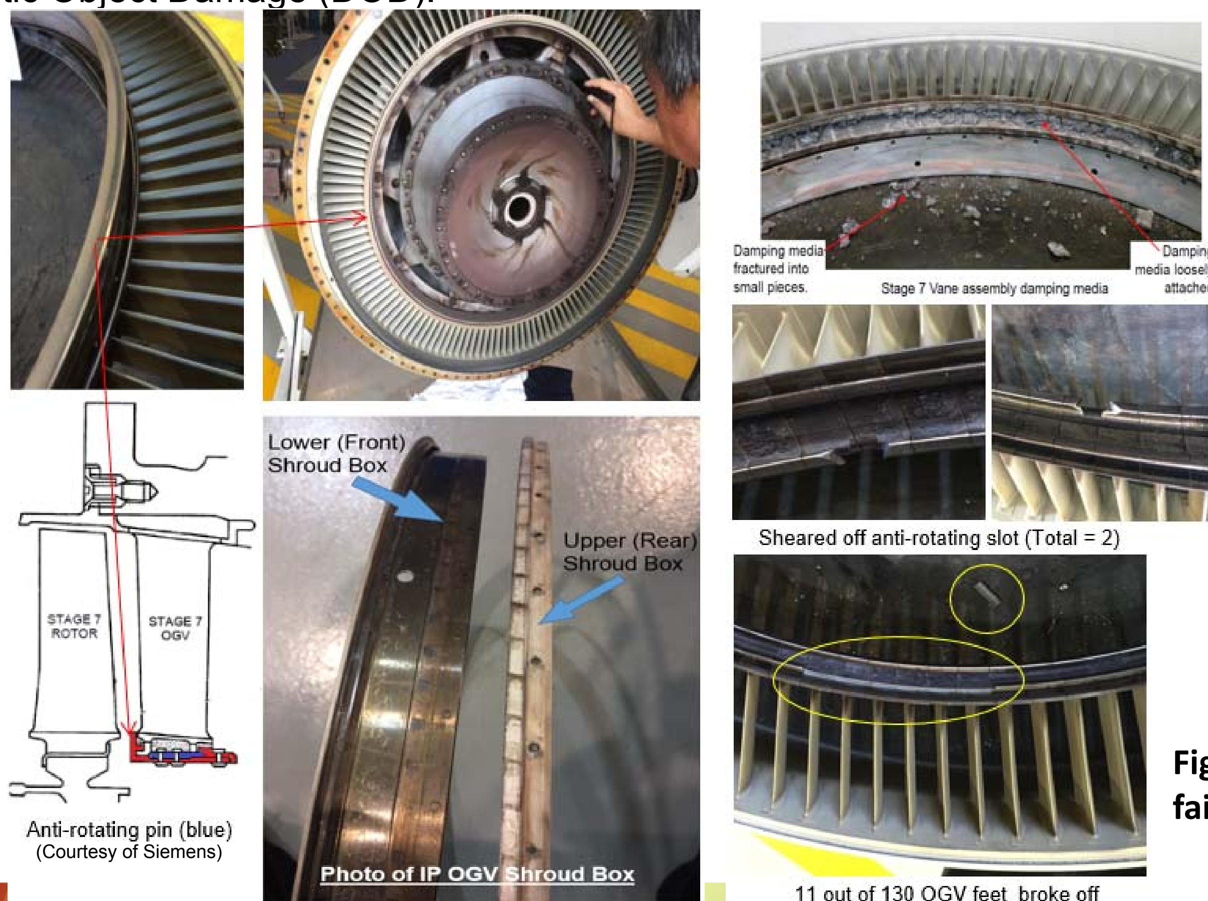

Fig 3: Images from first failed DOD engine

Early Detection of Second Engine Failure

1. Using trends from first failure, algorithms were developed for online **E**quipment **H**ealth **M**onitoring (EHM) early detection.
2. This was triggered on a second engine when GG performance started to deteriorate beginning **23rd Jan 2017** per below.
3. The IP compressor trends indicated normal deterioration but the HP compressor showed rapid performance deterioration.

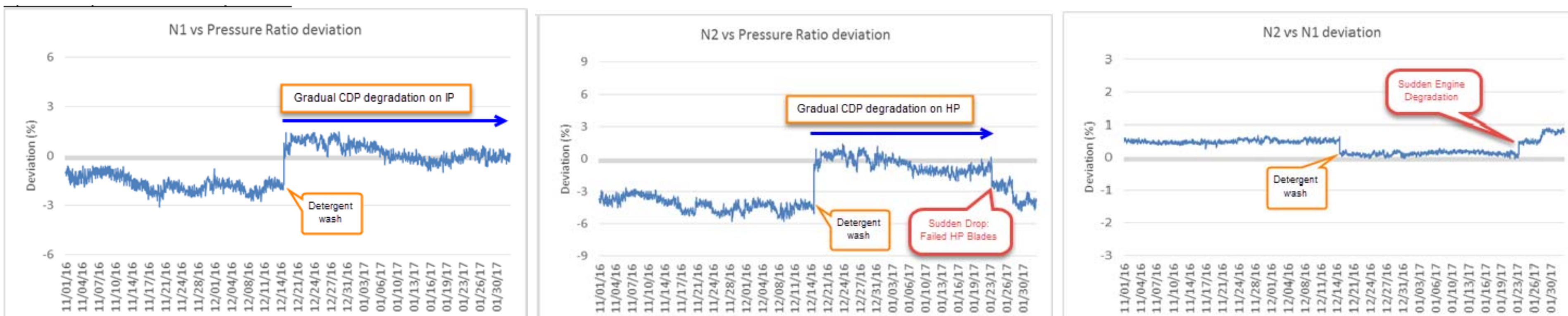

Fig 4: Surveillance trends from second failed DOD engine

Early Detection of Second Engine Failure (Cont’d)

4. Engine boroscope performed subsequent to **EHM** notification confirmed HPC blade damage.

Fig 5: Boroscope images showing damaged HPC blades

Historical IP Compressor OGV Operating Temperature for Failed Engines

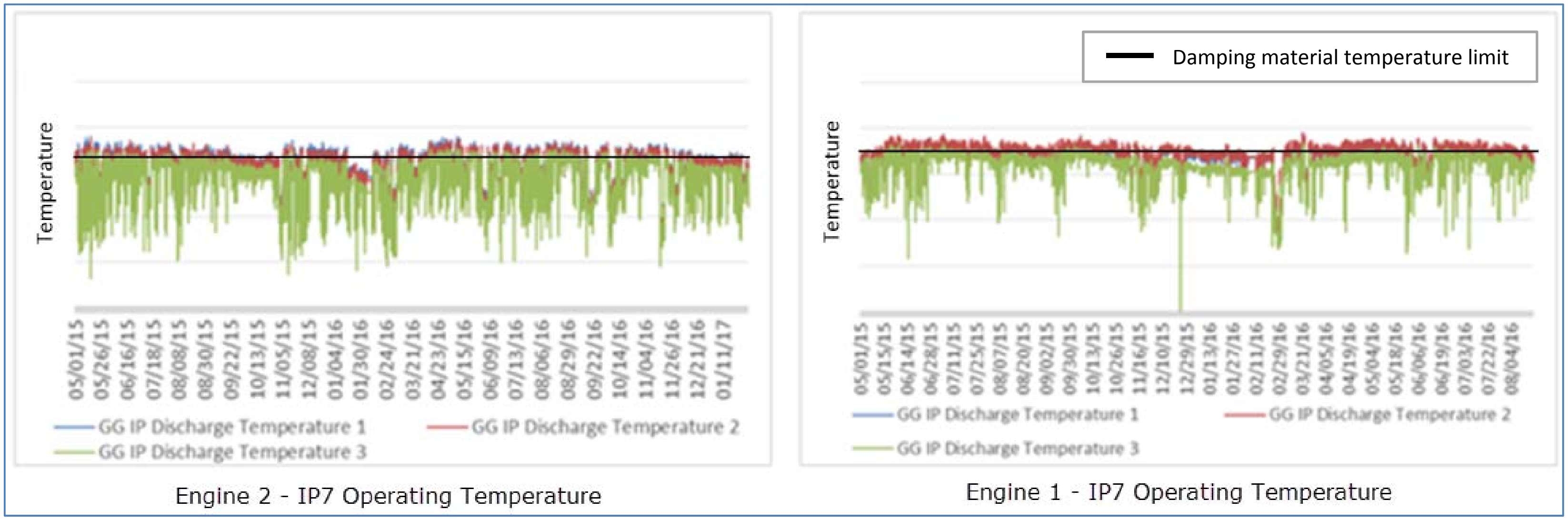

Fig 6: Temperature trending at IP OGV area for both failed DOD engines

Engine IP discharge temperature (IP7) trends showed that discharge temperature for both failed engine exceeded the working temperature threshold of the damping material.

High Ambient Temperature Environment

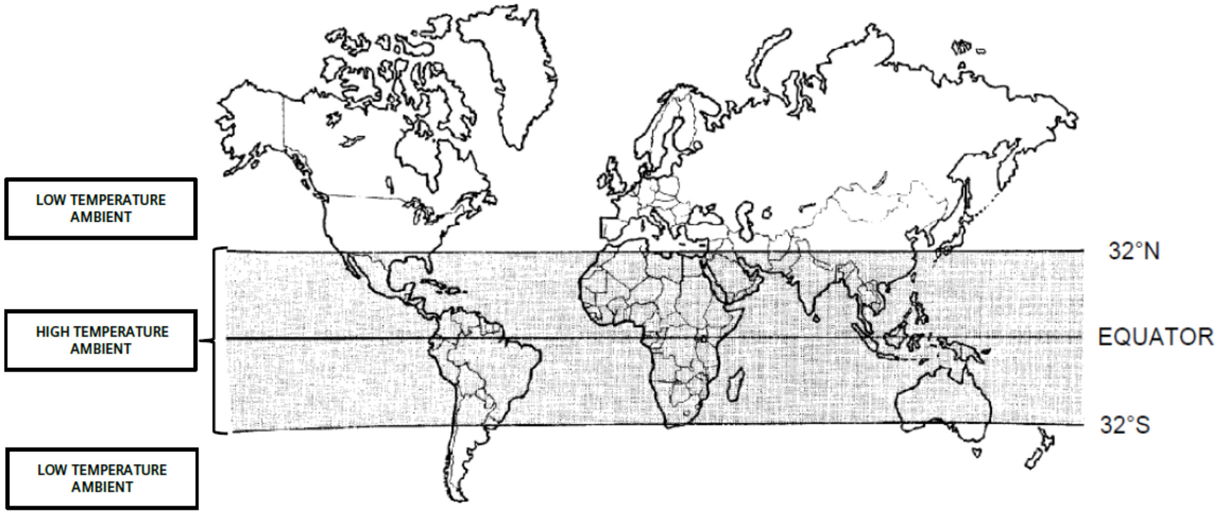

Fig 7: Definition of HIGH / LOW temperature ambient

- Even in this high ambient environment, we have had good fleet reliability, often exceeding OEM overhaul recommendation
- To maintain high reliability, OEM was actively involved to investigate the root cause and implement the solution

Working Theory of Failure

Analysis of failed engines indicated **high ambient temperature environment** combined with **maximum power operation** AND **repeated use of shroud box** after engine overhauls contributed to the accelerated wear. The engine failure progression is as below:

1. The shroud box is retained in position by the rubber 'glue'.
2. At around 12k hours the rubber has completely degraded and no longer retains the shroud box.
3. If the clearance is greater than 'new' limits then rattling wear takes place. Proposed containment action prevents engine failure cycle at this point.
4. The wear progresses to the square of the clearance, with the shroud box moving forwards.
5. The rotational rattling movement of the shroud box wears through the anti-rotation strips or loosens its rivets until they fall out.
6. Eventually the shroud box is free to rotate increasing the wear. Finally the shroud box clearance is sufficient for it to contact the IP rotor.
7. Both conditions can rotate the shroud box, wearing through the vane feet and releasing debris into the gas stream causing Foreign Object Damage (FOD) to the HPC blades. The damage can continue until the actual shroud box itself breaks up causing severe engine DOD.
8. From point 3 to 7 is estimated to take around 6,000 hours on full load engines that have not had the containment actions applied.

Wear Mechanism on Shroud Box

Rattling Wear on Shroud Box

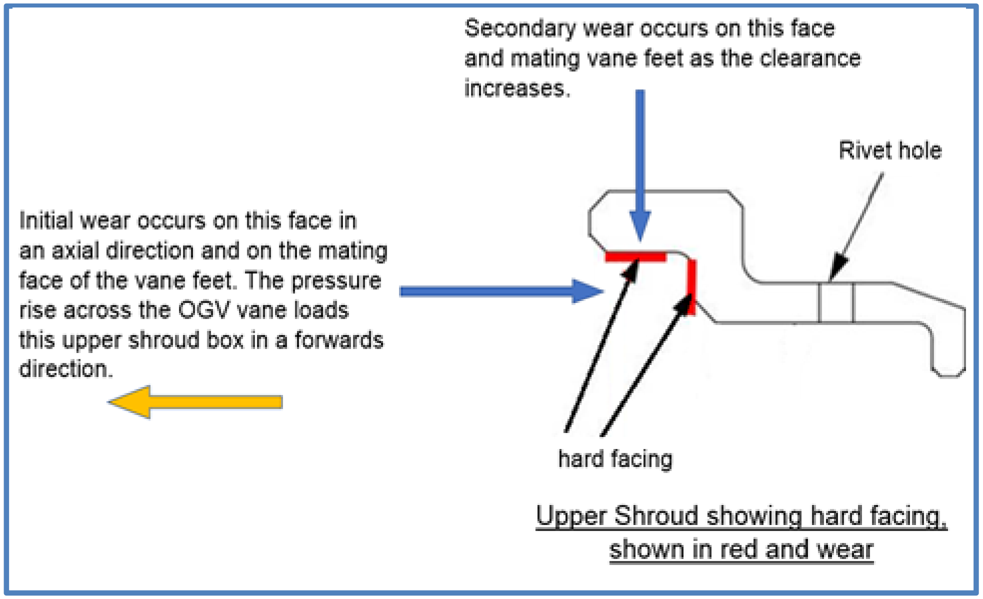

Fig 8: Wear areas on upper shroud box caused by rattling

Rotational Movement of Shroud Box

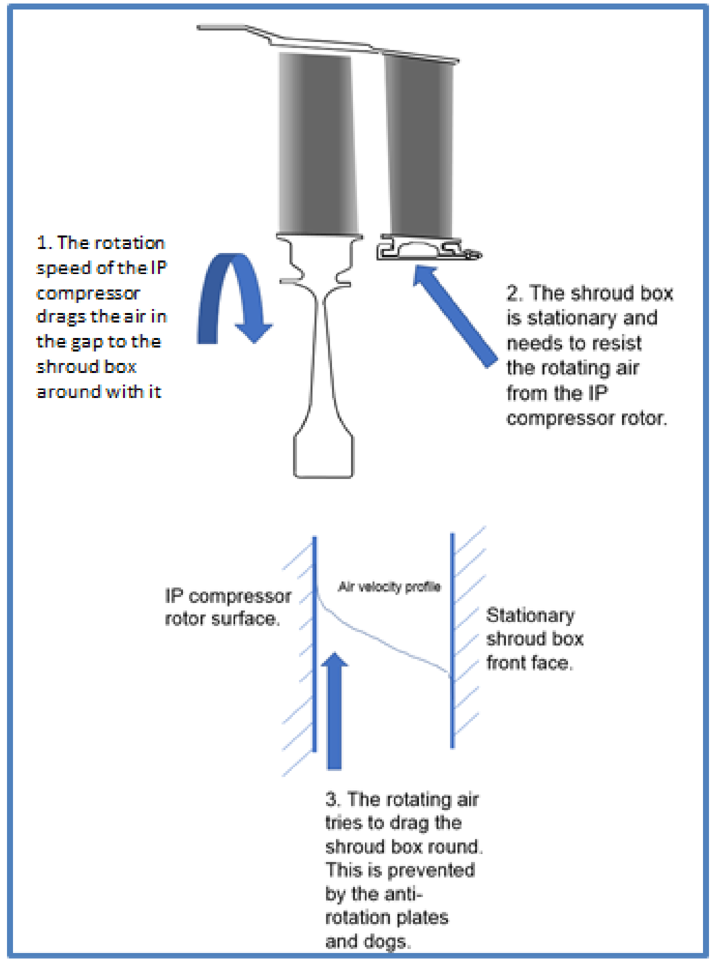

Fig 9: Rotational movement of shroud box

OGV Shroud Box Wear vs Engine Hours Operated

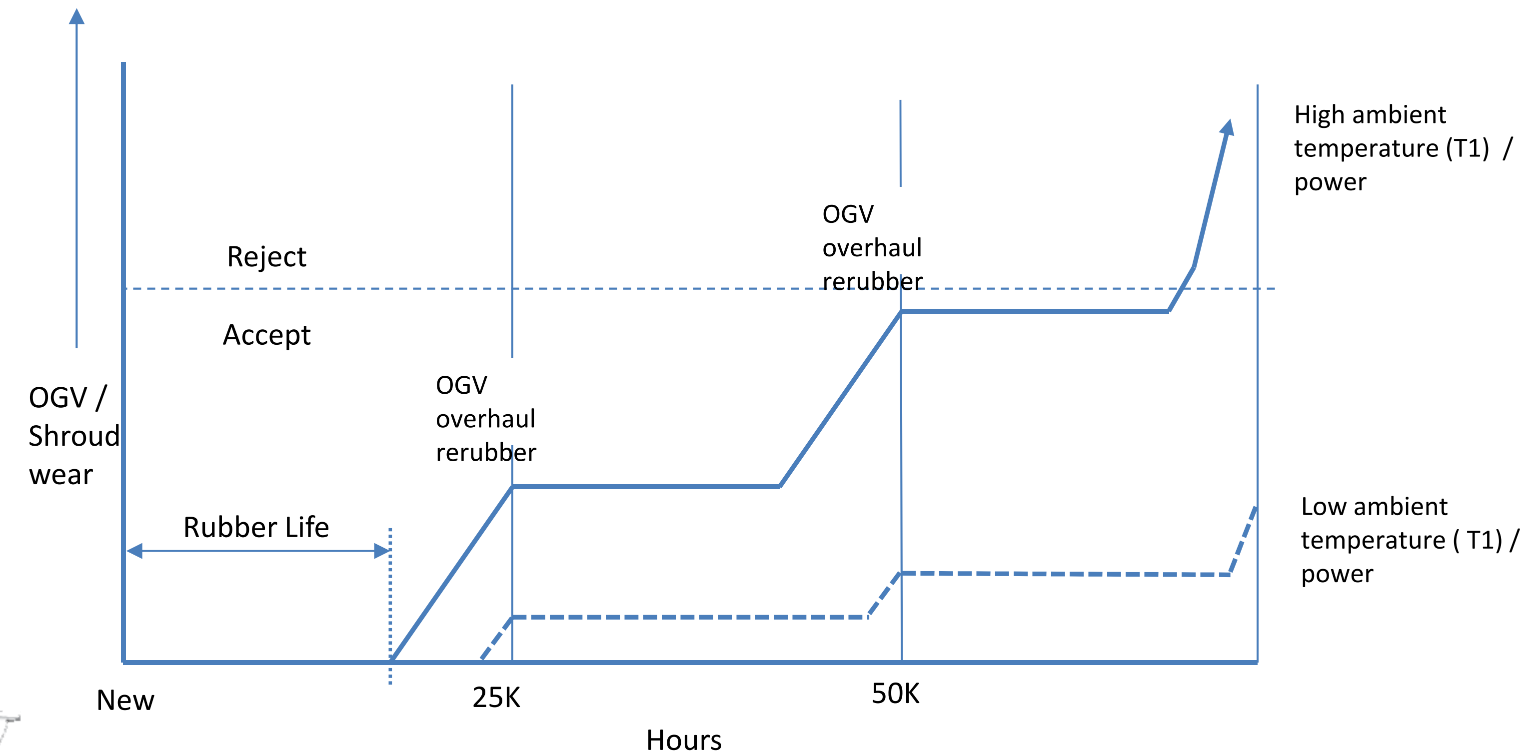

Fig 10: Wear on OGV shroud box against hours in operation and effect of ambient condition

Path Forward

- The past acceptance standards for the shroud box could allow reuse of part with no hard coating remaining.
- Hence, OGVs are rebuilt to 'as new' limits. This will allow achieving the target life expectancy with least likelihood of an engine failure.
  - The vane feet are returned to new condition as there is a repair scheme to do this.
  - OEM has issued revised inspection limits for the shroud box, components with no hard coating are replaced.
- We have screened our engine fleet and identified high risk engines that require interim OGV change-out to prevent an unplanned engine failure.

Risk Priority and Forward Plan

Priority	No. of OGV o/h	High Power	Low Power	Risk
1	3	*		High
2	2	*		High
3	1	*		Med
4	3		*	Med
5	2		*	Low
6	1		*	Low
7	0	*	*	No risk

Table 1: Illustration of perceived risk versus OGV overhauls and Engine Power

Engine failures are accelerated when:

- Running at topping / high power
- Number of times OGV has been reused

Review of existing installed units:

History of each engine Serial Number in the fleet was analyzed for:

- OGV change-out history
- Hours on the OGV (Total, High Power vs Low Power)

	Engine 1		Engine 2	
	xx TrA	16,000	xx TrB	26,830
	xx TrC	20,000		
	40,513	36,000	38,195	26,830
	yy TrA	26,217	xx TrA	25,000
			xx TrC	506
	41,318	26,217	41,530	25,506
	yy TrB	18,449	yy TrA	33,000
	42,598	18,449	41,164	33,000
			xx TrC	18,354
Low power		20,000		52,336
High Power run hours		60,666		51,354
Total Run Hours TSN		80,666		103,690

Conclusion

- Analysis of failed engines indicated **high ambient temperature environment** combined with **maximum power operation** AND **repeated use of shroud box** after engine overhauls contributed to accelerated wear.
- OEM responded and took corrective actions :
  - Issued a bulletin to all operators updating them on the issue with interim measure to fully repair the OGV assembly at every overhaul.
  - Issued revised shroud inspection limits to be used at overhaul shops.
  - OEM confident proposed corrective actions will address future failures.
  - OEM redesigning assembly to improve reliability and extend time between maintenance.
- Lessons Learned:
  - Repeated use of wearing parts on aging fleets can potentially result in engine failures
  - Operators having an open communication channel with OEM helps to quickly identify root cause and path forward. This can be achieved via joint-investigations.
  - OEM's need to have an interest to continuously improve their product line where applicable.
  - Design & process improvement is a continuous process, including on matured fleets and established product lines.
  - Share learning with others to prevent repeat engine failures.